A Two-Dimensional Vehicle-Media Interaction Model For Wheeled Vehicles

By

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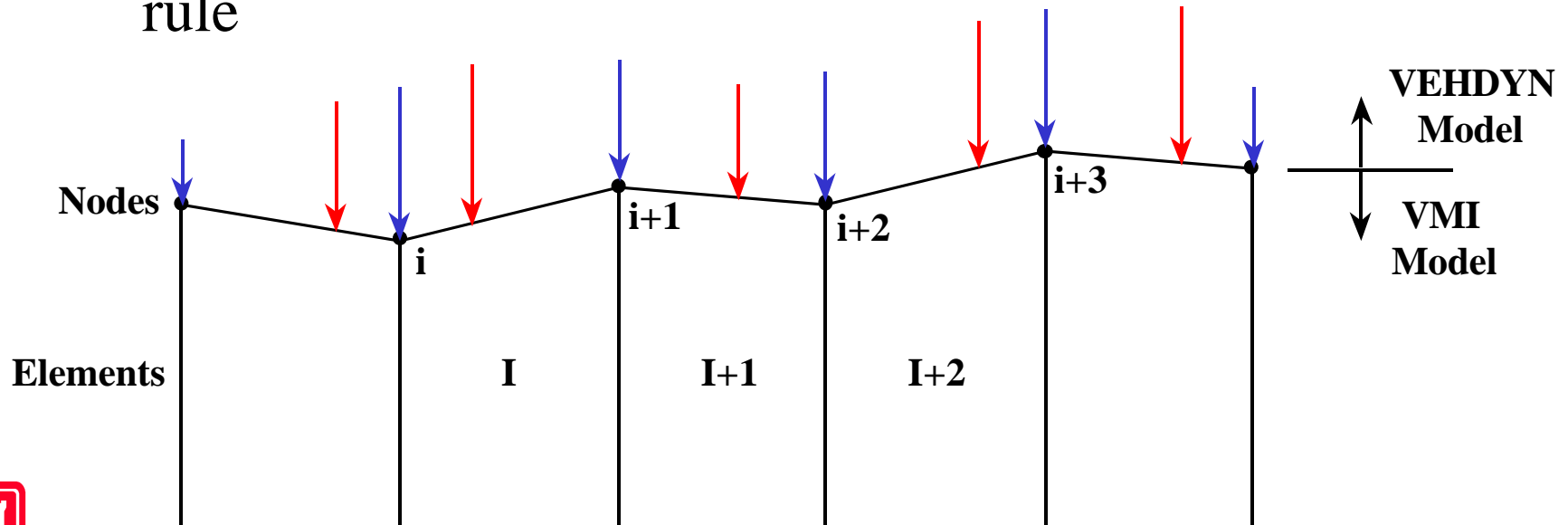Robert E. Walker (ARA, Inc.)

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Deformable Terrain: Interface

- Interface Between VEHDYN and VMI Models

  – RED Arrows: Forces applied by vehicle to terrain elements from vehicle dynamics model (VEHDYN)

  – BLUE Arrows: Distribution of elemental (RED) forces to individual VMI element nodes using 50/50 rule

Deformable Terrain: Methodology

- RED Elemental forces are result of VEHDYN's tire model interacting with instantaneous terrain profile.

- VMI is solved using BLUE boundary forces (possibly many times per VEHDYN time step) to determine net interface deformation during current VEHDYN time step.

- Each VMI ground element has its own property profile (as input). A loading history is maintained for each element and node. This history is stored at regular intervals to a restart file for multiple pass use.

- Nodal displacements from VMI define the instantaneous terrain profile at start of each VEHDYN time step.

Deformable Terrain: HMMWV Example

- M998 HMMWV over Soft Flat Profile
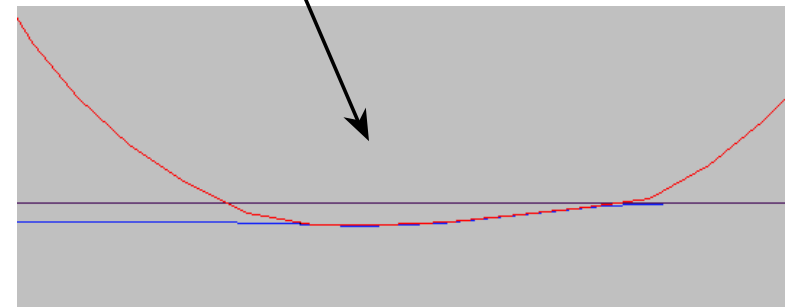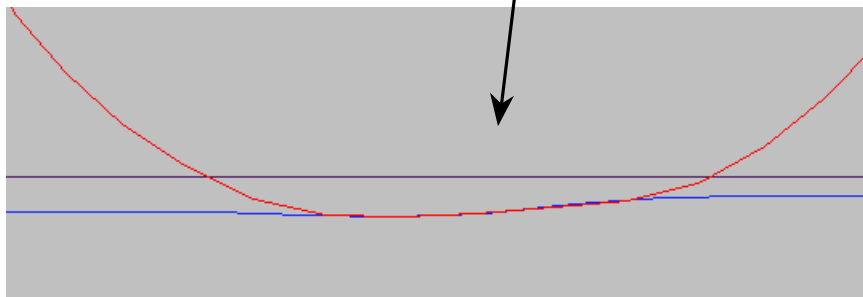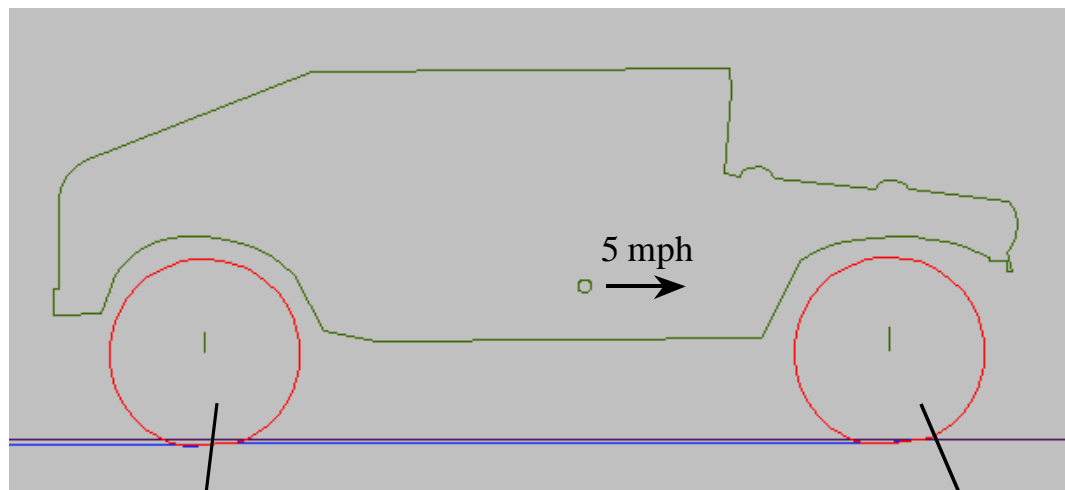
VEHDYN Horizontal DOF: Traverse Simulation

- Currently, vehicle moves "magically" at constant speed.

- To implement traverse simulation capability via VEHDYN, the ability to accelerate/decelerate is required to adjust the vehicle's forward speed as traction requirements/availability change.

- A horizontal degree of freedom at the vehicle's center of gravity provides for a non-zero horizontal acceleration by solution of the equation $F_H = ma_H$.

- This horizontal equation of motion is integrated to provide the instantaneous (changing) horizontal speed component.

Typical course layout for data collection and validation testing
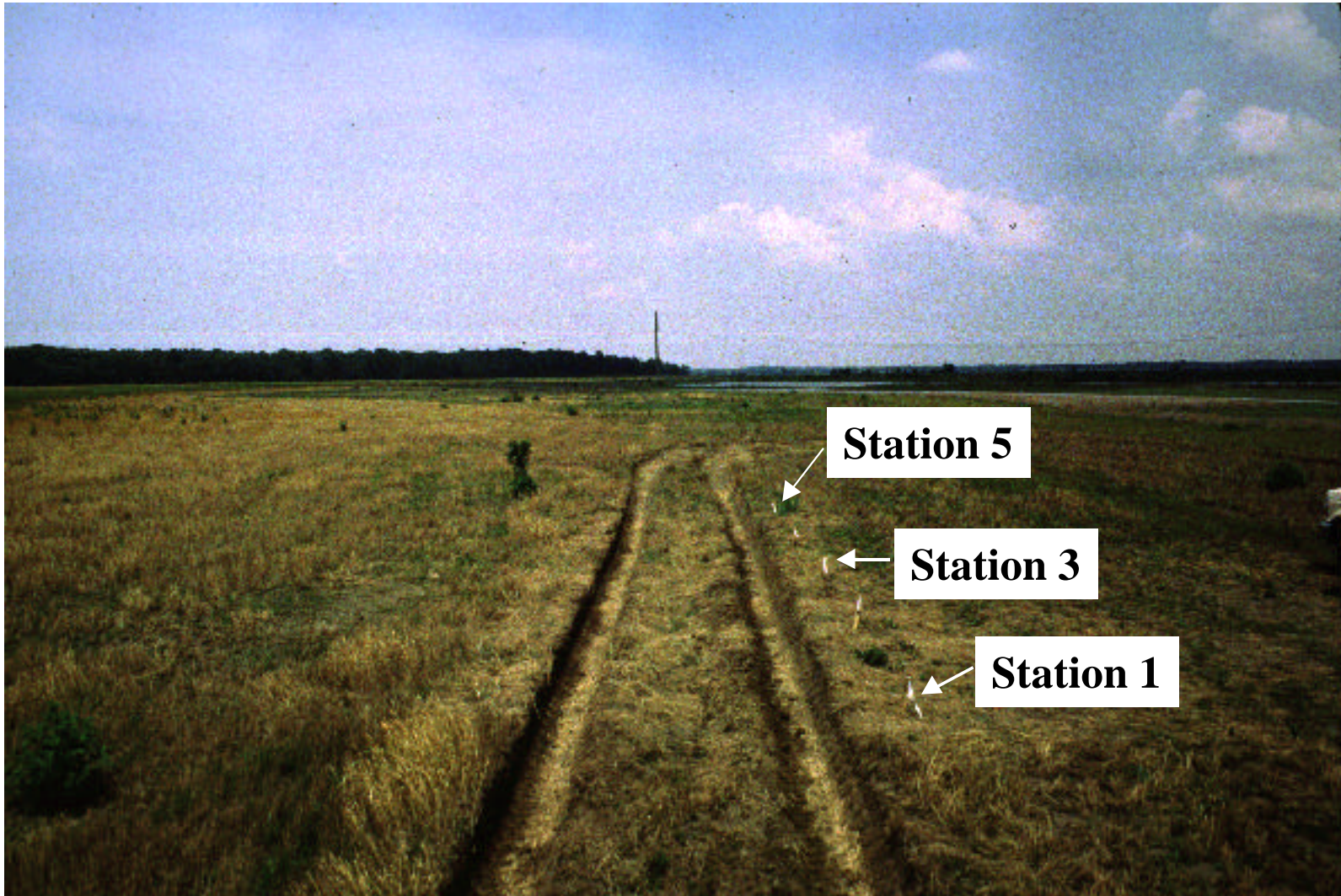
M1078 LMTV used in validation testing

Rutting formed by LMTV used in validation testing
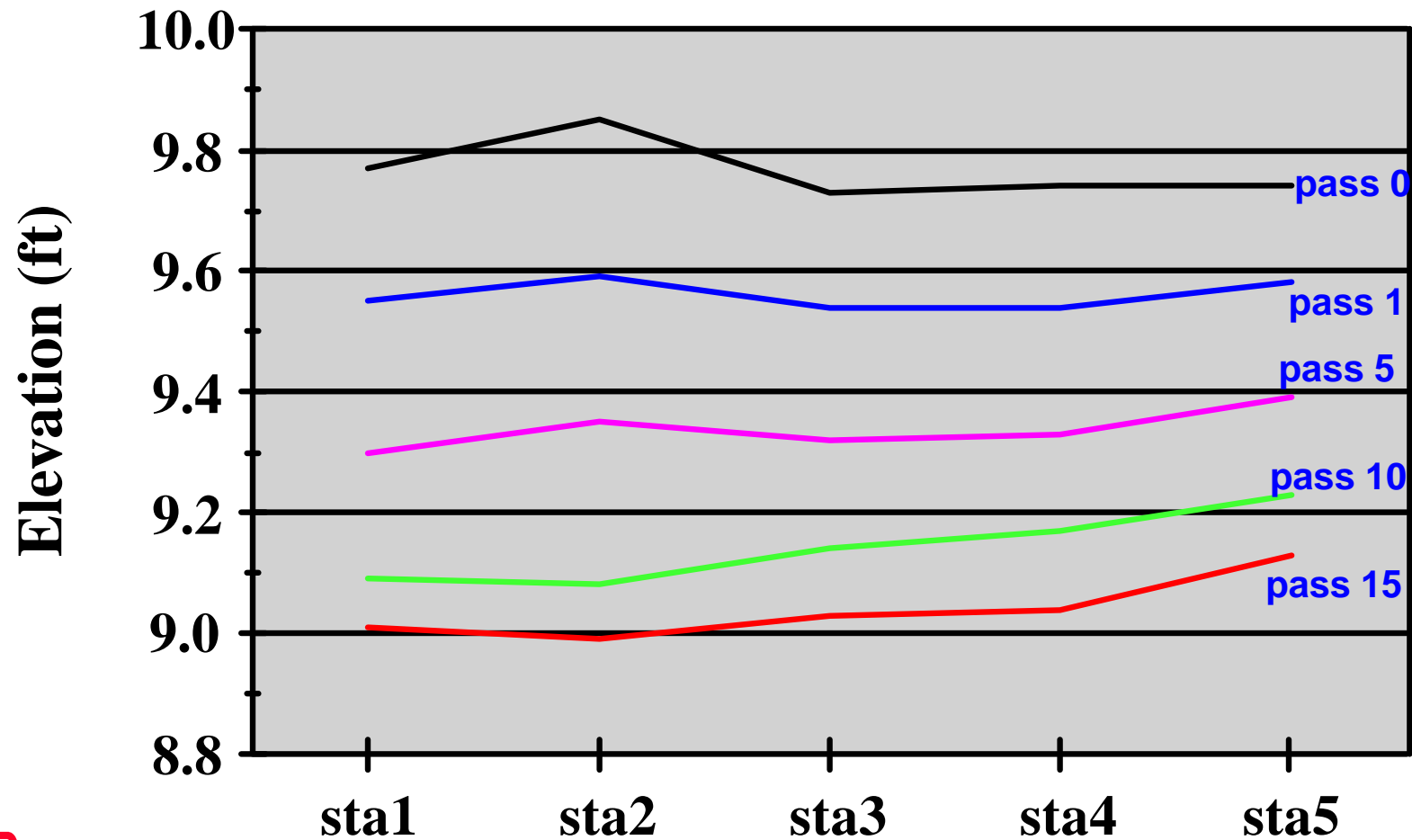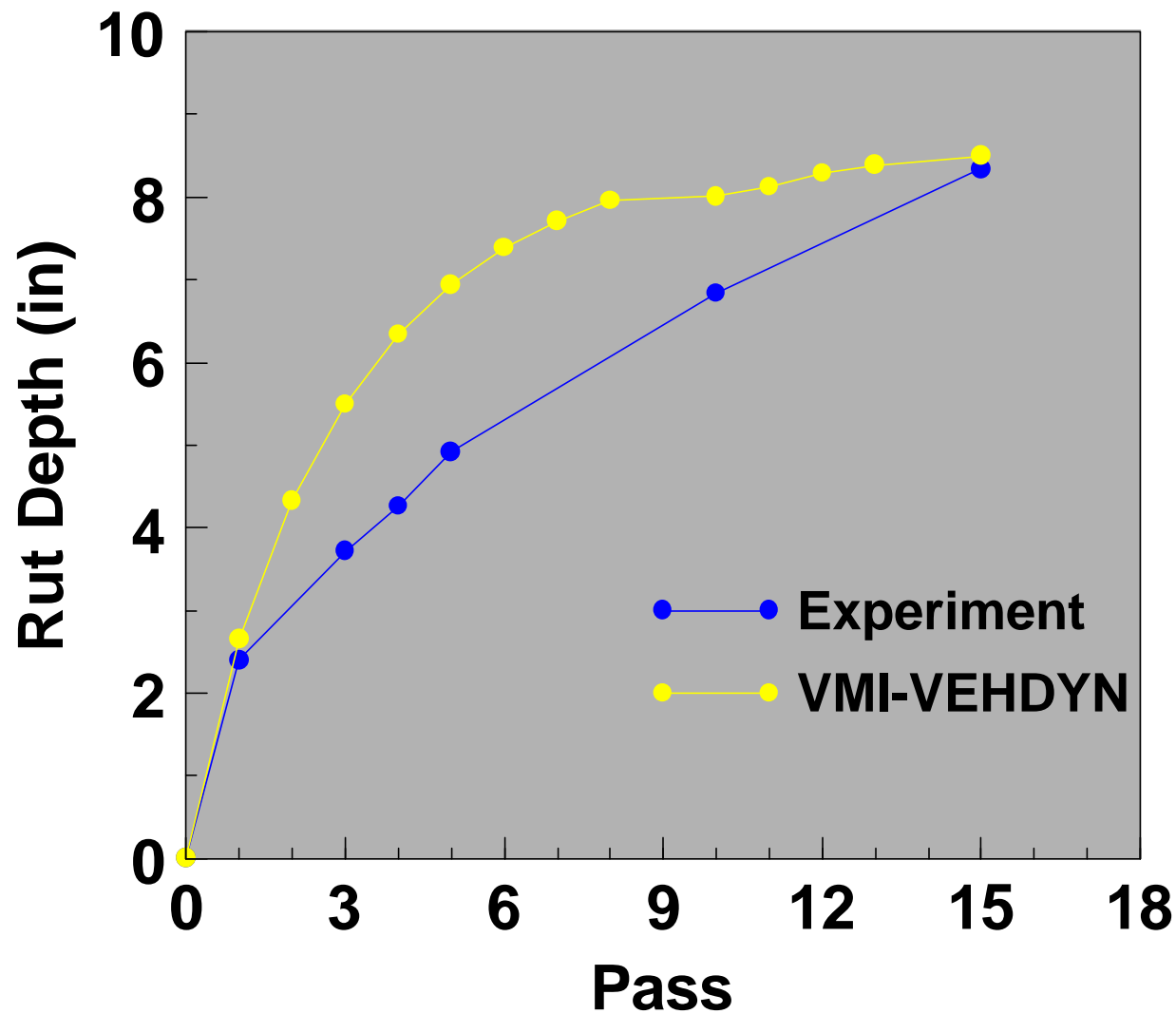
LMTV Multiple-Pass Rutting Data at Yazoo City, MS
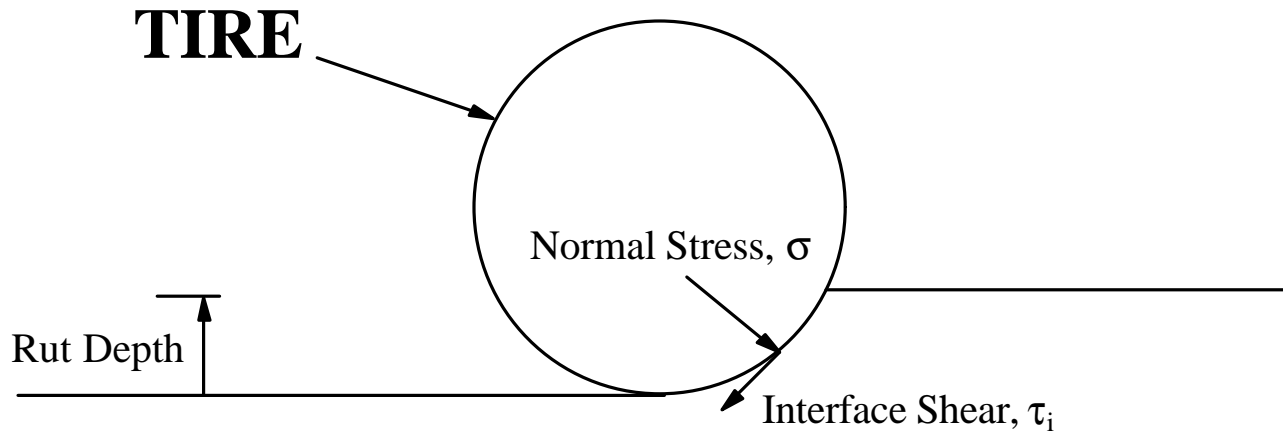
Unloaded LMTV Truck Over Buckshot Clay at 2 MPH

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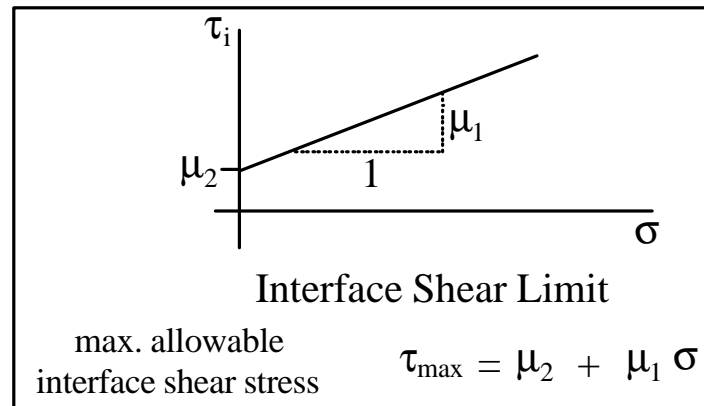# Field Test vs Calculation For LMTV at Yazoo Clay Site

Relevant Force Components For Traction Resistance

TIRE

Normal Stress, σ

Rut Depth

Interface Shear, τ_i

SOIL

τ_i

μ_1

μ_2

1

σ

Interface Shear Limit

max. allowable
interface shear stress

$$\tau_{max} = \mu_2 + \mu_1 \sigma$$

$$J_i \ ' \ D c_s \left(V_t \ \& \ \frac{dx}{dt} \right) \quad , \quad {}^*J_i^* \ \# \ J_{max}$$

VMI Force Components at Tire-Soil Interface

TIRE

Normal Stress, σ

Rut Depth

Horizontal Force

Interface Shear, τ_i

Vertical Force
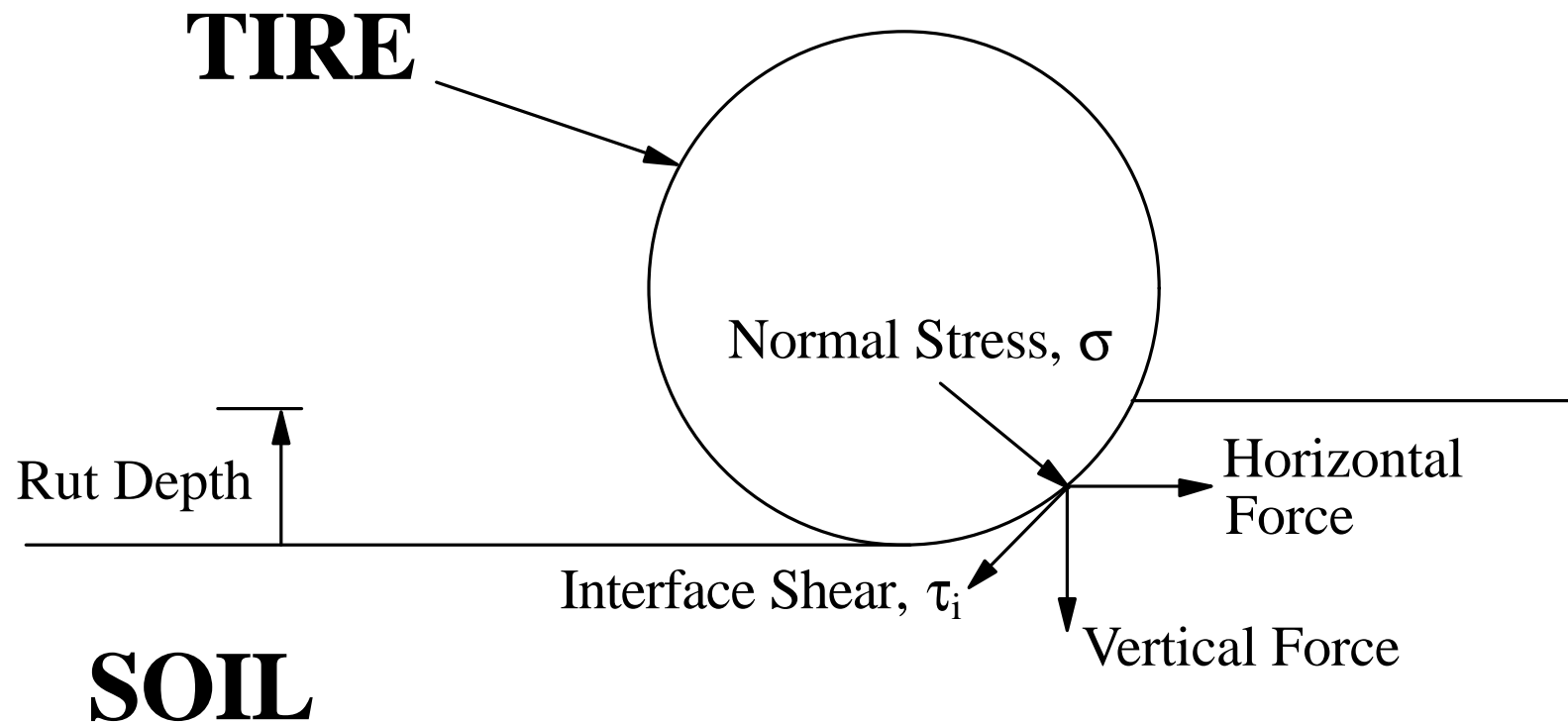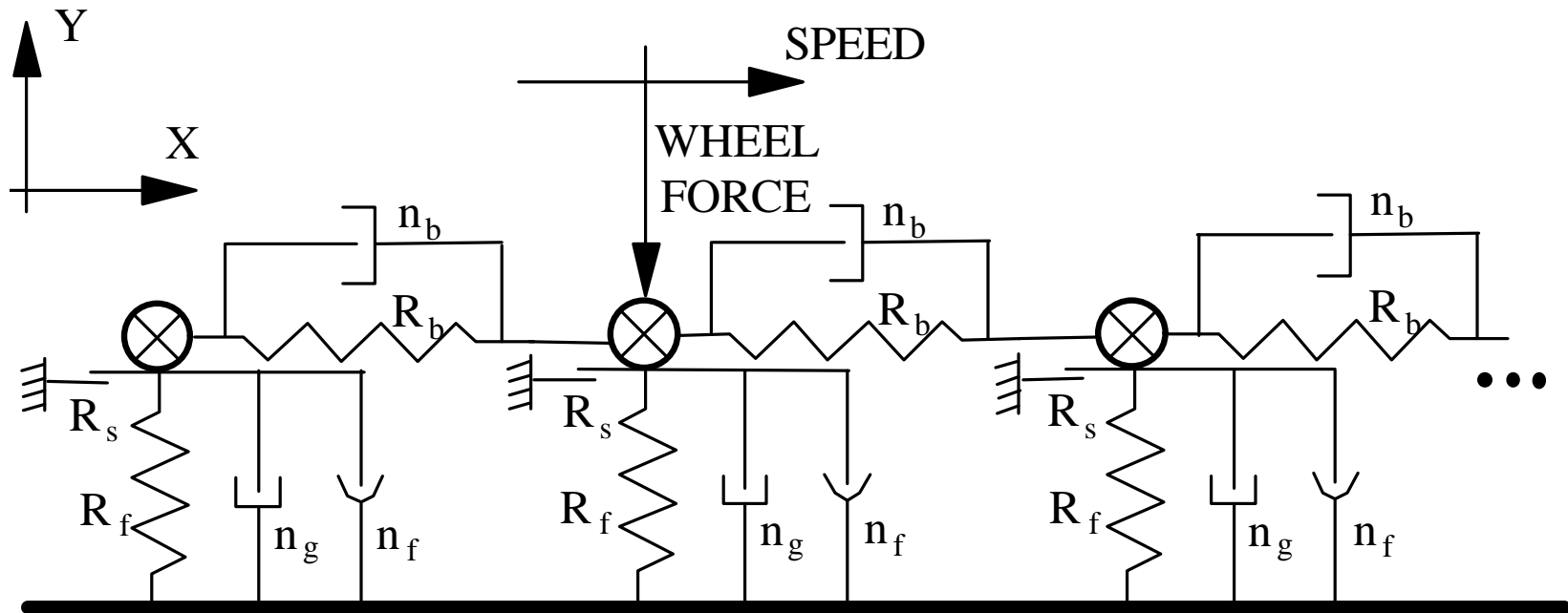
SOIL

Total Horizontal Force = Motion Resistance

VMI model schematic : Dynamic Footing Analogy

R_b = motion resistance function n_g = radiation damper

R_f = soil rutting function n_f = flow damper

R_s = soil traction function n_b = internal damper

Local Normal Sinkage Model

$$F = A Q^B$$

$$Q = \text{normalized sinkage} = \left(\frac{\text{rut depth}}{\text{tire width}} \right)$$

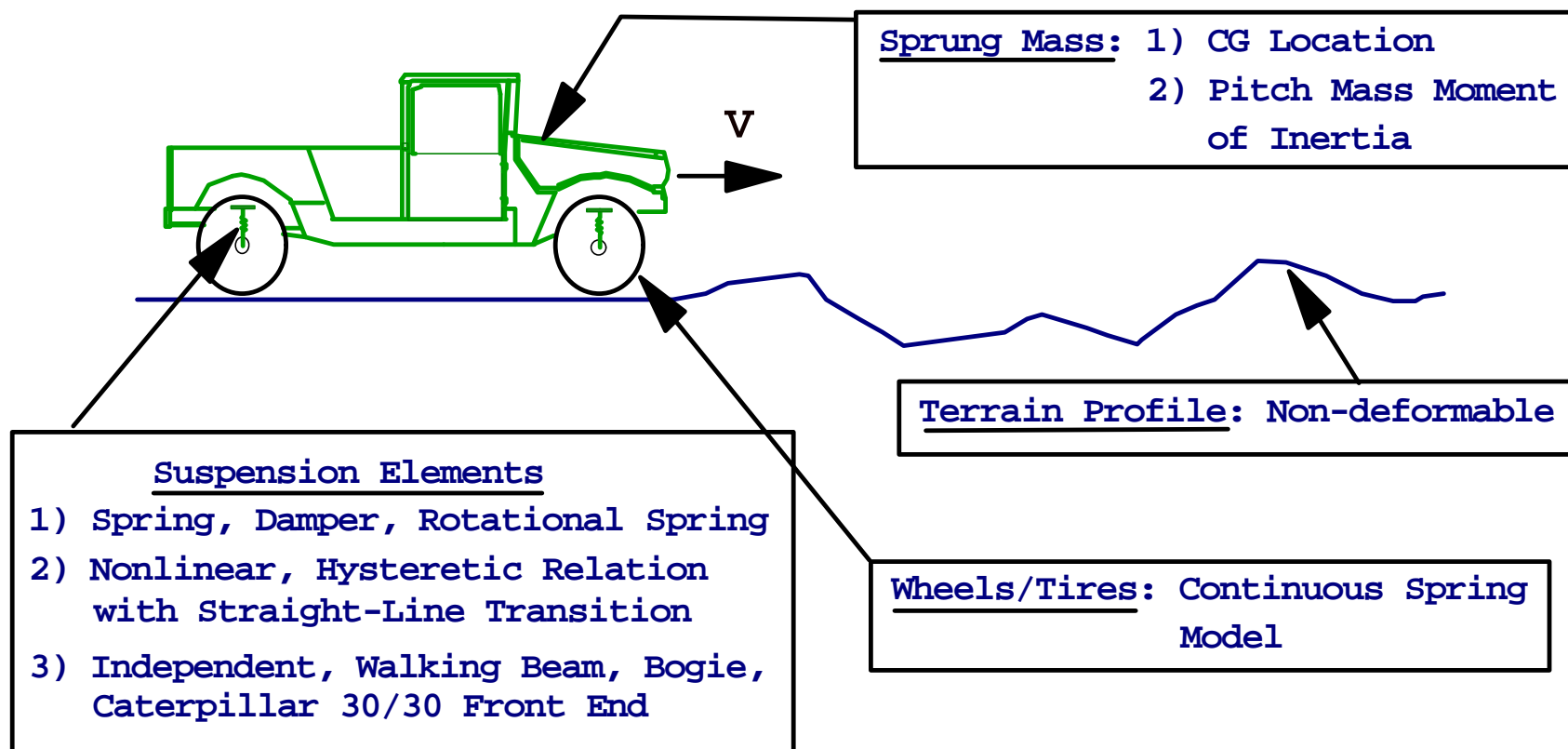$$F = \text{normalized soil resistance}$$

$$F \begin{cases} W / C \, (bL) & \text{(clay soils)} \\ W / G \, (bL)^{3/2} & \text{(sandy soils)} \end{cases}$$

Soil Type	A	B
Clay	1.0021	0.7160
Sand	0.3519	1.1062

VEHDYN Vehicle Dynamics Model

V

Sprung Mass: 1) CG Location
2) Pitch Mass Moment of Inertia

Terrain Profile: Non-deformable

Suspension Elements

1) Spring, Damper, Rotational Spring
2) Nonlinear, Hysteretic Relation with Straight-Line Transition
3) Independent, Walking Beam, Bogie, Caterpillar 30/30 Front End

Wheels/Tires: Continuous Spring Model
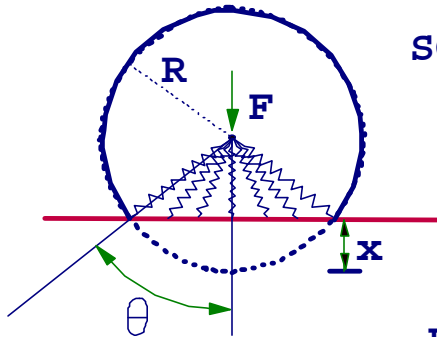
VEHDYN Spring Element
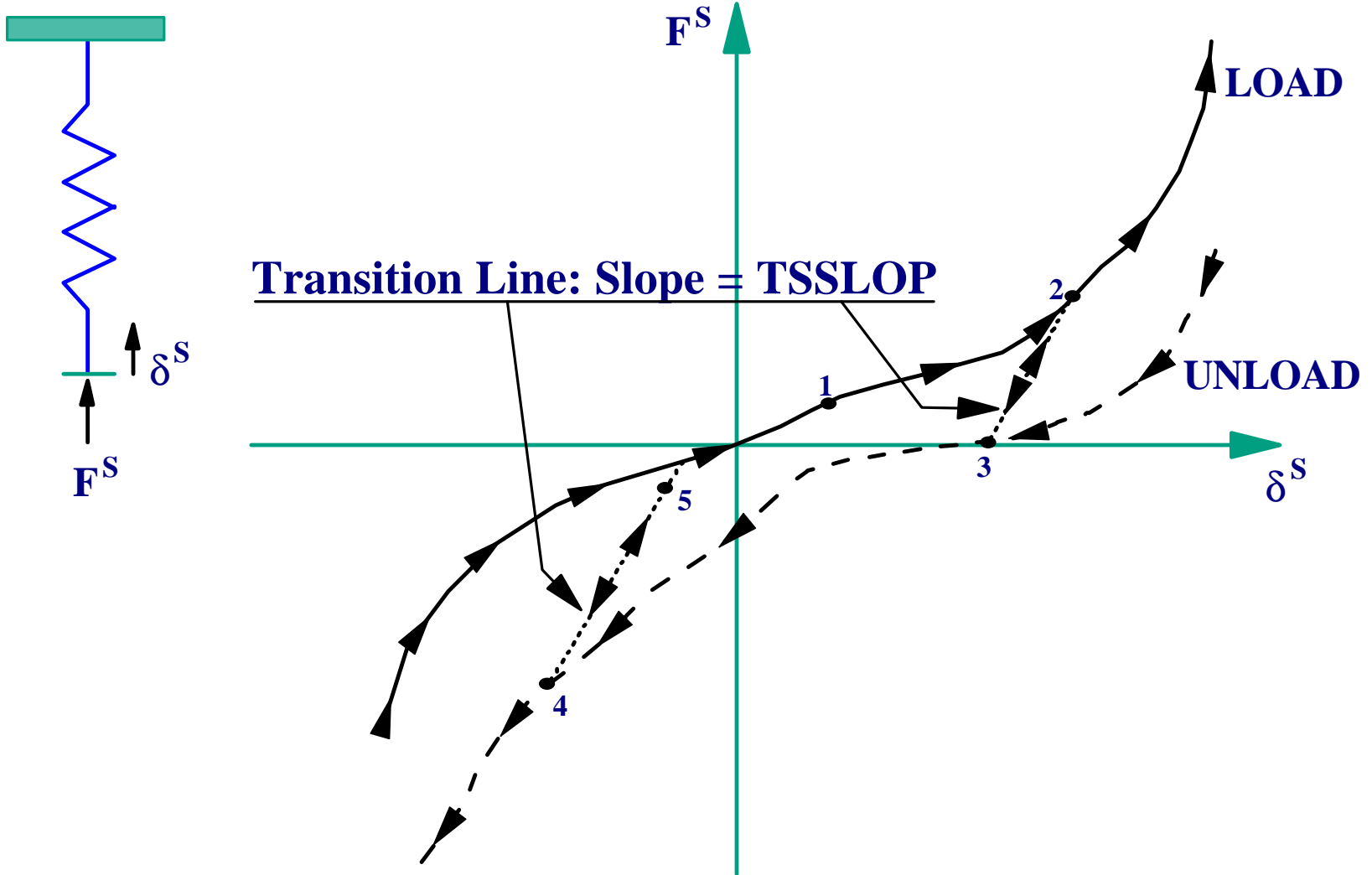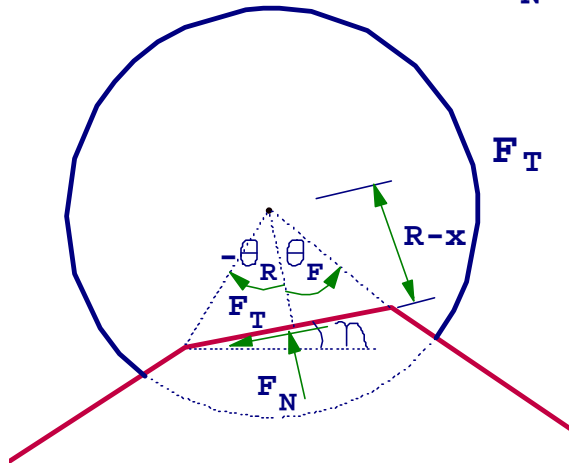
VEHDYN Continuous Spring Model For Tires

SC = Radial spring stiffness per unit angle

$$= \frac{F}{2(R\sin\theta - \theta(R-x))}$$

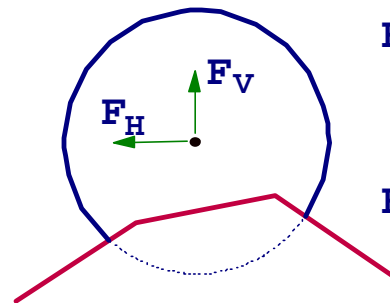F_N = Normal force component

$$= SC[R(\sin\theta_F - \sin\theta_R) - (R-x)(\theta_F - \theta_R)]$$

F_T = Tangential force component

$$= SC[R(\cos\theta_R - \cos\theta_F) + (R-x)\ln(\frac{\cos\theta_F}{\cos\theta_R})]$$

F_H = Horizontal force comp.

$$= \sum F_N \sin\eta + F_T \cos\eta$$

F_V = Vertical force comp.

$$= \sum F_N \cos\eta - F_T \sin\eta$$

VMI Normal Damping

Soil Flow Damping $n_f ' C_D D v^2$

   $C_D ' $ drag coefficient

   $D ' $ soil wet density

Soil Radiation (Newtonian) Damping $n_g ' C v$

   $C ' $ critical damping coefficient $ ' 2 . \sqrt{KM}$

   $v ' $ soil normal particle velocity at VMI interface
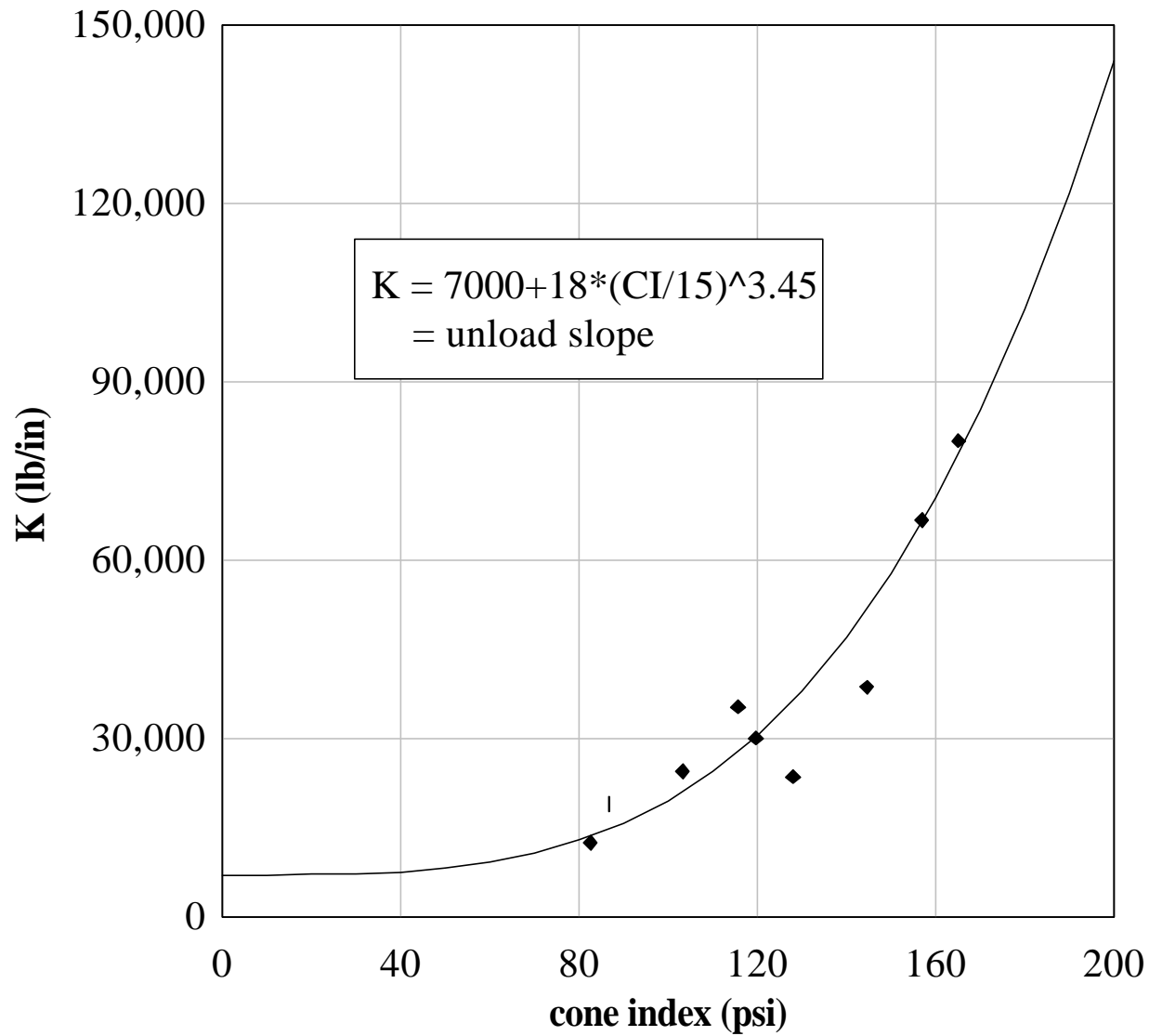
   $. ' $ damping ratio

   $K ' $ unloading stiffness (Figure 3)
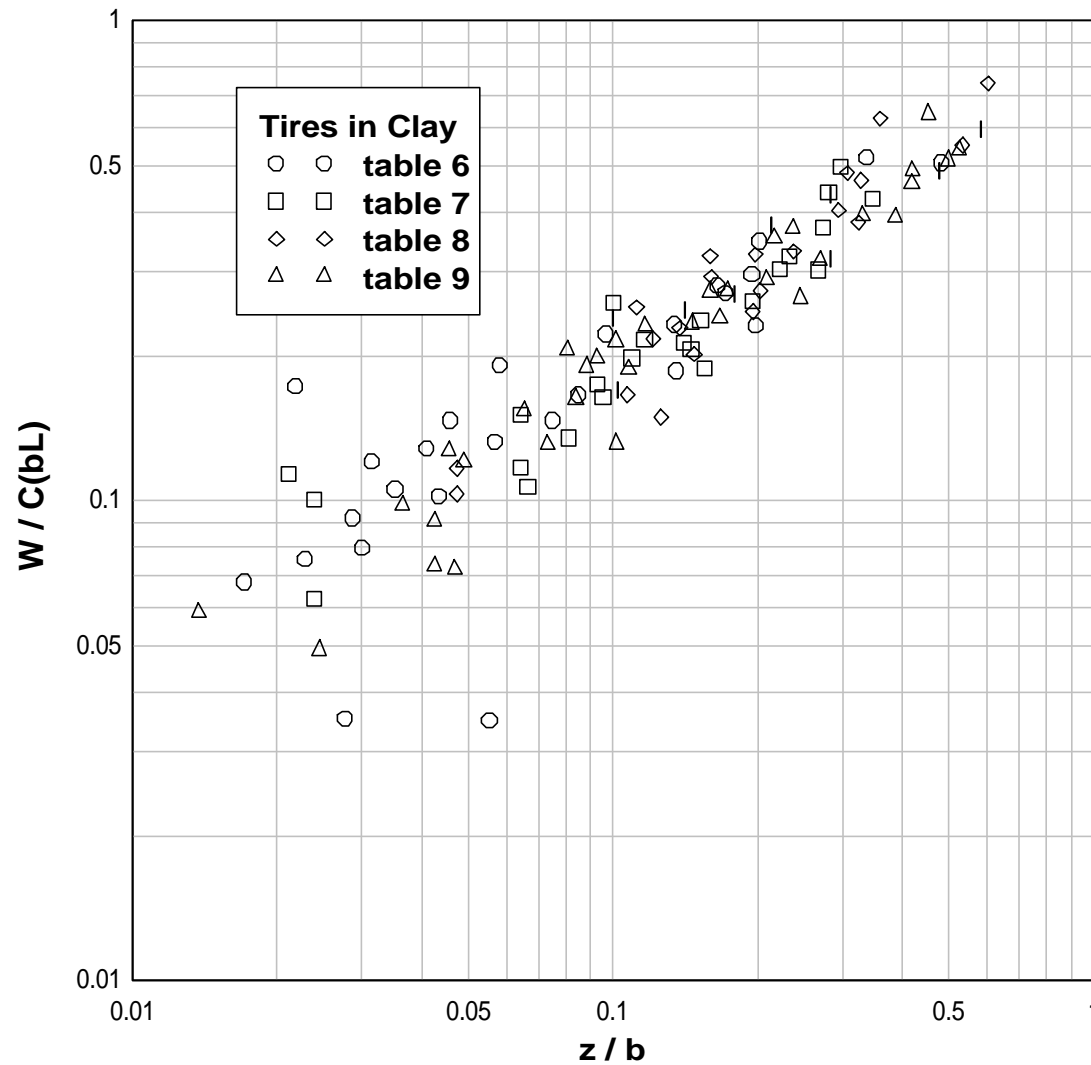
   $M ' $ mobilized mass moving with VMI interface
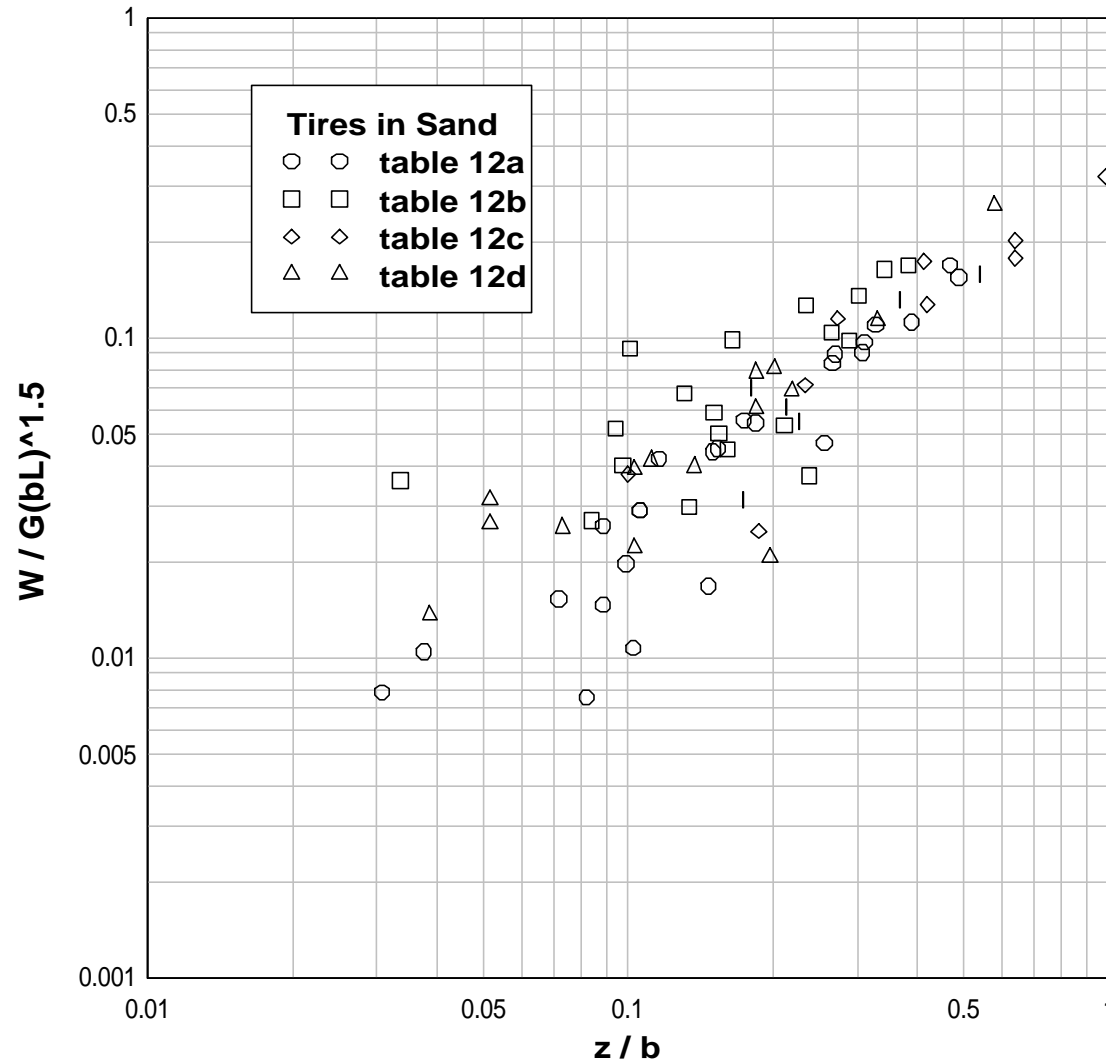
Functional Fit to Unloading Stiffness Data to Obtain K

$$K = 7000 + 18*(CI/15)^{3.45}$$
$$= \text{unload slope}$$

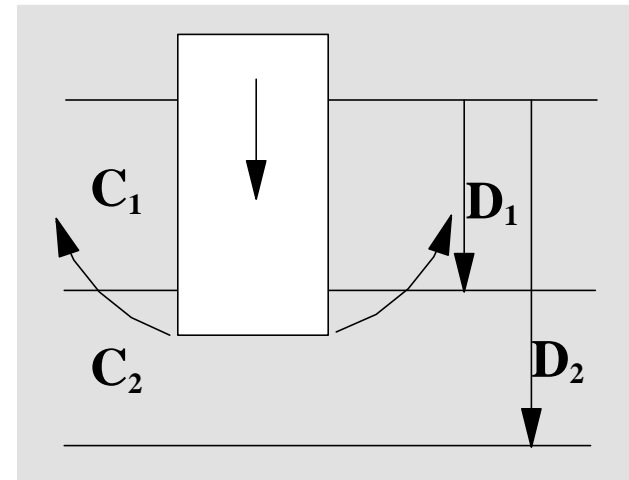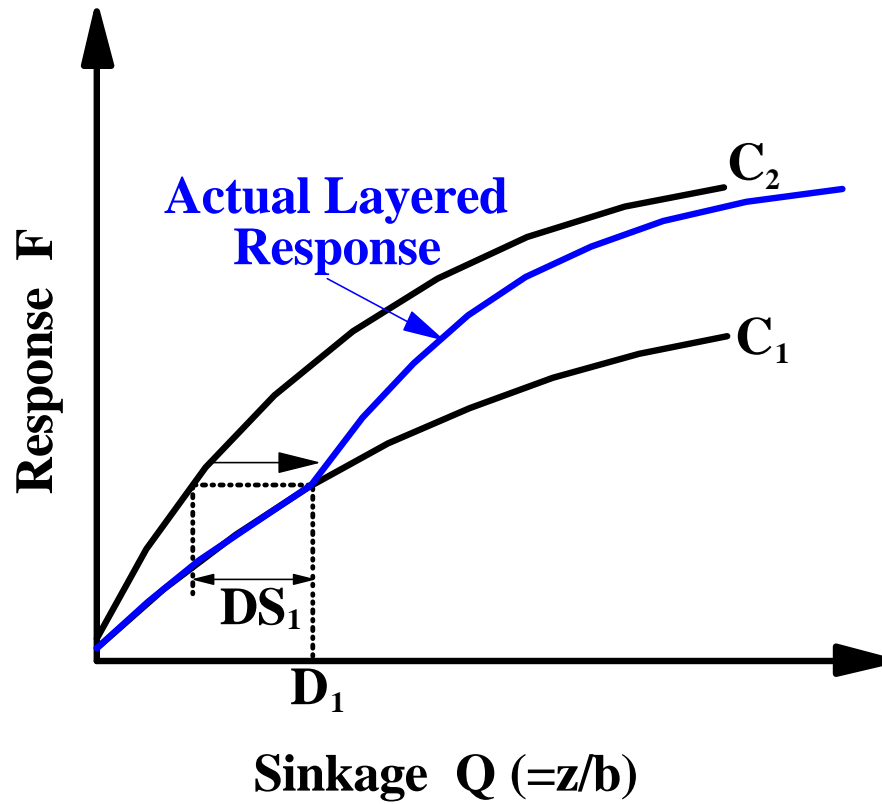*K (lb/in)* vs *cone index (psi)*

Data of Soil Resistance Acting on Tires in Clay

Data of Soil Resistance Acting on Tires in Sand

Vertical Soil Layering Model

$$F = \begin{cases} A_i \, Q^{B_i} & , \quad 0 < Q < D_i \\ A_{i\%1} \, (Q \& D_i \% DS_{i\%1})^{B_{i\%1}} & , \quad D_i < Q < D_{i\%1} \end{cases}$$

Longitudinal Load-Unload Model and Mobilized Mass

$$F_x = \begin{cases} U \cdot \Delta x \, , & F_x \# F_U \\ F_U \, , & F_x > F_U \end{cases}$$

F_x = longitudinal force

U = unload slope

Δx = differential longitudinal displacement

F_U = ave. CI $\times$ cross section A

$M = D A L$ = mobilized mass

A = longitudinal cross section = $2 r_o b$

D = soil wet density

r_o = footprint equivalent circular radius

b = tire width

L = VMI grid spacing

Additional Force and Layering Modifications

•**Tire embedment:**

$$\frac{K}{K_o} = 2 - e^{\frac{H_Y}{r_o}}$$

K = effective soil stiffness
K_o = original soil stiffness
H_Y = rut depth
r_o = equivalent contact area radius

•**Load-Unload Cycling From Mult-Pass:**

$$CI = CI_o \left\{ (RI - 1.)\left(1. - e^{-n}\right) + 1. \right\}$$

CI = new cone index
CI_o = original cone index
RI = remold index
n = no. load-unload cycles

•**Layer Thickness Reduction:**

$$\Delta t = t_o \left(1 - \frac{H_Y}{pivot} \right)$$

Δt = layer thickness reduction
t_o = orig. layer thickness
pivot $\approx$ 2 × footprint length